Pedosphere **21**(1): 124–131, 2011
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Lignite-Derived Humic Acid Effect on Growth of Wheat Plants in Different Soils*1

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(Received July 10, 2010; revised November 19, 2010)

ABSTRACT

Humic acid (HA), a fairly stable product of decomposed organic matter that consequently accumulates in ecological systems, enhances plant growth by chelating unavailable nutrients and buffering pH. We examined the effect of HA derived from lignite on growth and macronutrient uptake of wheat (*Triticum aestivum* L.) grown in earthen pots under greenhouse conditions. The soils used in the pot experiment were a calcareous Haplustalf and a non-calcareous Haplustalf collected from Raisalpur and Guliana, respectively, in Punjab Province, Pakistan. The experiment consisted of four treatments with HA levels of 0 (control without HA), 30, 60, and 90 mg kg^{-1} soil designated as HA_0, HA_1, HA_2, and HA_3, respectively. In the treatment without HA (HA_0), nitrogen (N), phosphorus (P), and potassium (K) were applied at 200, 100, and 125 mg kg^{-1} soil, respectively. Significant differences among HA levels were recorded for wheat growth (plant height and shoot weight) and N uptake. On an average of both soils, the largest increases in plant height and shoot fresh and dry weights were found with HA_2 (60 mg kg^{-1} soil), being 10%, 25%, and 18%, respectively, as compared to the control without HA (HA_0). Both soils responded positively towards HA application. The wheat growth and N uptake in the non-calcareous soil were higher than those of the calcareous soil. The HA application significantly improved K concentration of the non-calcareous soil and P and NO_3-N of the calcareous soil. The highest rate of HA (90 mg kg^{-1} soil) had a negative effect on growth and nutrient uptake of wheat as well as nutrient accumulation in soil, whereas the medium dose of HA (60 mg kg^{-1} soil) was more efficient in promoting wheat growth.

Key Words: calcareous soil, NO_3-N, nutrient uptake, plant height, soil nutrient

Citation: Tahir, M. M., Khurshid, M., Khan, M. Z., Abbasi, M. K. and Kazmi, M. H. 2011. Lignite-derived humic acid effect on growth of wheat plants in different soils. *Pedosphere*. **21**(1): 124–131.

INTRODUCTION

Calcareous soils are among the most key factors that limit the nutrient availability and agricultural production over 600 million ha of cultivable soils worldwide (Leytem and Mikkelsen, 2005). Soil properties that support plant growth, either physical such as moisture relations or chemical such as fertility and nutrient availability, are significantly affected by the calcareousness of the soils (FAO, 1973). The surfeit of calcium carbonate retards availability of nutrients by influencing soil pH. Ammonia volatilization and reduced solubility of phosphorus occur in these types of soils.

The calcareous soils in warmer regions are naturally low in organic matter due to high temperature. Humic substances (humic and fulvic acids) are a vital constituent and an intimate part of soil organic matter (Stott and Martin, 1990). Collectively they are called as humus, a term widely used for them as synonymous for soil organic matter (SOM) (Chen and Aviad, 1990). Humic substances are readily found in soils (Mackowiak *et al.*, 2001) and influence plant growth both directly and indirectly (Nardi *et al.*, 2002; Cimrin and Yilmaz, 2005). They have indirect influences on plant growth because they can improve soil properties such as aggregation, aeration, permeability, water holding capacity, hormonal activity, microbial growth, organic matter (OM) mineralization, and solubilization and availability of microelements (*e.g.*, Fe, Zn, and Mn) and some macro elements (*e.g.*, K, Ca, and P) (Chen and Aviad, 1990; Ayuso *et al.*, 1996; Sharif *et al.*, 2002). Directly, they affect the processes associa-

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ted with the uptake and transport of humic substances into the plant tissues (Chen and Aviad, 1990; Escobar *et al.*, 1996; Nardi *et al.*, 2002).

Humic substances improve yield and quality of a variety of plants, including grains (Wang *et al.*, 1995; Ayuso *et al.*, 1996; Sharif *et al.*, 2002; Vaughan and Linehan, 2004; Jones *et al.*, 2007; Ulukan, 2008). The yield of crops with organic materials could be achieved equally as compared to that with the application of NPK fertilizers. For example, HA applied at rates of 50–300 mg kg^{-1} was found to significantly increase root and shoot biomass in potted corn, with the rates of 50–100 mg kg^{-1} resulting in the highest growth response (Sharif *et al.*, 2002). Humic substances improve soil fertility by modifying the physical, chemical, and biological conditions in soil (Atiyeh, 2002; Atiyeh *et al.*, 2002; Albayrak and Arnas, 2005; Ayaş and Gülser, 2005; Natesan *et al.*, 2007). They affect the solubility of many nutrient elements by building complex forms or chelating with metal cations (Lobartini *et al.*, 1997; Verlinden *et al.*, 2009). As a consequence, the use of humic substances has often been proposed as a method to improve crop production (Adani *et al.*, 1998).

Lignite is an important precursor of HA. Lignite carbon may remain in soil due to low decomposition rate (Robertson and Morgan, 1995) and have impact on the quantity and composition of the SOM (Schmidt *et al.*, 1996; Rumpel *et al.*, 1998a, b). In a country like Pakistan, where soils are deficient in organic matter (0.3–1.0 g kg^{-1}), exploitation of natural resources (lignite) will be a major step towards economic sustainability of the cropping system. Pakistan is rich in lignite which has sizeable amounts of HA that can be extracted and utilized effectively as organic fertilizer to boost up agricultural production. HA may be utilized in agriculture as fertilizer, plant growth promoter, nutrient carrier, and soil conditioner (Nisar and Mir, 1989). Therefore, a study was undertaken to access the effect of lignite-derived HA on growth and mineral nutrient uptake of wheat and soil nutrient status in both calcareous and non-calcareous soils of major wheat growing regions of Pakistan.

MATERIALS AND METHODS

Extraction and analysis of humic acid

Lignite from the Thar Coal Mine, Sindh Province, Pakistan, were ground and passed through a 60-mm sieve, and then treated with an oxidizing agent (100 mL L^{-1} HNO_3) added in small doses at specific intervals to prevent rise in temperature to above 40 °C due to exothermic oxidation with external cooling in laboratory. The coal residues were then treated with alkali (0.5 mol L^{-1} NaOH). The water soluble salt of HA thus formed was dissolved into a solution which was filtered through Whatman No. 42 filter paper through vacuum suction to separate it from insoluble organic residues. The solution was evaporated to dryness on a water bath (Hai and Mir, 1998) and stored until use in the laboratory.

Soil sampling

The soils used in the experiment were collected from 4 different fields selected in Raisalpur and Guliana, Punjab Province, Pakistan: Two of them represented a Raisalpur soil (calcareous Haplustalf, Soil Survey Staff, 1999), while the other two represented a Guliana soil (non-calcareous Haplustalf, Soil Survey Staff, 1999). The fields were mostly used for growing rainfed maize and wheat from last several years. The soil samples were taken from top 15 cm from 20 different locations at random from each field, mixed to make composite soil samples representative of each soil series, and then air dried and sieved through a 4-mm mesh screen. The basic physical and chemical characteristics of the soils were analyzed using standard methods (Table I).

TABLE I

Basic properties of the two soils used in the experiment

Property	Raisalpur soil (calcareous)	Guliana soil (non-calcareous)
$pH_{(1:1)}$	7.5	7.4
Electrical conductivity(dS m^{-1})	0.50	0.68
HCO_3 (g kg^{-1})	50	50
Cl (cmol kg^{-1})	3	3
Exchangeable Ca + Mg (cmol kg^{-1})	4.5	6.1
$CaCO_3$(g kg^{-1})	152	56
NO_3-N (mg kg^{-1})	0.08	0.07
P (mg kg^{-1})	6.48	2.2
K (mg kg^{-1})	88	144
Na (mg kg^{-1})	36	42

Pot experiment

A pot experiment was conducted in the greenhouse of the Land Resource Research Programme (LRRP), Institute of Natural Resources and Environmental Sciences (INRES), National Agricultural Research Centre (NARC), Islamabad, Pakistan, during the 3rd week of January 2009. Thoroughly cleaned earthen pots of 15 cm wide and 20 cm height were used. The pots were grouped into two sets: 12 for the Raisalpur soil and 12 for the Guliana soil. Four levels of humic acid

(HA) were designated as treatments in three replications, *i.e.*, 0 (control without HA, HA_0), 30 (HA_1), 60 (HA_2), and 90 (HA_3) mg kg^{-1} soil. In the treatment HA_0, nitrogen (N), phosphorus (P), and potassium (K) were applied at 200, 100, and 125 mg kg^{-1} soil, respectively. The pots were labeled according to their respective treatments and arranged in a complete randomized design (CRD) of two factors (HA levels and soils). About 300 g air dried, sieved (4-mm mesh) soil was filled in each pot. HA was dissolved in distilled water and applied as foliar sprays, using a knapsack sprayer, before sowing. The test crop used was wheat variety "Wafaq". The soil was moistened with water and maintained at 60% of its water holding capacity throughout the experiment. A destructive soil sample was taken from root zone after every second day prior to watering the pots. The gravimetric moisture contents were determined and percent loss in water was corrected by adding water.

In each pot, six healthy and uniform seeds of wheat were sown at a depth of 2 cm. The pots were kept under shade to reduce evapotranspiration during the course of germination. After complete germination, plants were thinned to 3 plants per pot. Plants from each pot were harvested 30 d after germination. Plant height, shoot fresh weight (SFW), and shoot dry weight (SDW) were determined. Shoot dry weight was taken after oven drying at 70 °C for 3 d. Dried shoots were then milled, air dried, and sifted (2-mm mesh). Total N was determined by Kjeldahl method (Bremner and Mulvaney, 1982). Wet combustion in a 2:1 mixture of HNO_3 and $HClO_4$ was used for mineral element analysis of the samples at a ratio of the mixed acid solution to the plant sample of 20:1 (Winkleman *et al.*, 1990). The phosphorus (P) content was determined by the vanadomolybdate yellow color method with a spectrophotometer (Shimadzu UV-1601) (John *et al.*, 2001). K and sodium (Na) were determined by flame emission (Horneck and Hanson, 1998).

Composite soil samples were collected accordingly after removal of plants from the pots. The soil samples were air dried and sifted (2-mm mesh) to eliminate plant materials and then stored in a cool and dry place until analyzed for pH, electrical conductivity (EC), P, K, Na, and NO_3-N. Soil pH was determined by a glass electrode on 1:1 (v/v) soil:water suspension after a 1-h equilibration period with occasional stirring. For determination of soil EC, a 1:2 soil to water mixture was shaken on a reciprocating shaker for 1 h, the filtrate was filtered by vacuum filtration, and then the extract was analyzed on an EC meter (Winkleman *et al.*, 1990). Available P was determined by the Olsen extraction method (Olsen and Sommers, 1982) and available K was extracted with 1 mol L^{-1} ammonium bicarbonate-diethlylenetriaminepentaacetic acid (AB-DTPA), adjusted to pH 7, and was determined flame photometrically (John *et al.*, 2001). After extracting soil samples with 200 mL of 1 mol L^{-1} KCl followed by filtration through Whatman No. 40 filter paper, mineral N (NH_4^+-N and NO_3^--N) of the extract was determined by using the steam distillation and titration method of Keeney and Nelson (1982). NO_3^--N was calculated by subtracting NH_4^+-N from total mineral N.

Statistical analysis

The data obtained were subjected to statistical analysis using the MSTATC statistical software (version 3.1) and the mean values were compared using least significant difference (LSD) multiple range test ($P \leq 0.05$) (Steel and Torrie, 1980).

RESULTS

Wheat growth

The plant heights and shoot weights of wheat as affected by the foliar application of different levels of HA in the calcareous and non-calcareous soils are given in Table II. Statistical analysis showed significant differences among HA levels ($P \leq 0.05$) for each soil type for plant height, shoot fresh weight (SFW), and shoot dry weight (SDW) (Table II). Similarly, plant height, SFW, and SDW showed significant differences for different HA levels and soils when averaged for their means. However, their interactions (HA × soil) did not show significance effect ($P \leq 0.05$) on growth parameter (Table II).

Results in Table II indicated that application of HA at 60 mg kg^{-1} (HA_2) in both soils affected plant height, shoot fresh weight, and shoot dry weight positively. However, the highest HA level (90 mg kg^{-1}) had a negative effect on growth of wheat in both soils. The highest plant height (30.2 cm), shoot fresh weight (3.1 g), and shoot dry weight (0.7 g) for the Raisalpur soil was obtained for the HA level of 60 mg kg^{-1}. Similarly, maximum values of plant height (34.2 cm), shoot fresh weight (4.3 g), and shoot dry weight (0.9 g) were found when 60 mg kg^{-1} of HA was applied in the Guliana soil. The average plant height was at par between HA_2 and HA_3 while the average shoot fresh and dry weights showed no significant differences among all HA levels. The soils had a significant ($P \leq 0.05$) effect on growth of wheat. The highest means of plant height (33.1 cm), shoot fresh weight (4.1 g), and shoot dry weight (0.9 g) were found in the Guliana soil other than the Raisalpur soil.

TABLE II

Effect of humic acid (HA) on growth of wheat plants grown in the Raisalpur (calcareous) and Guliana (non-calcareous) soils tested

HA level[a)]	Plant height			Shoot fresh weight			Shoot dry weight		
	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean
	cm			g					
HA_0	27.3c[b)]	30.1c	29.1c	2.4b	3.5b	2.9b	0.6ab	0.9ab	0.7ab
HA_1	28.9b	32.8b	30.8b	2.8a	4.0a	3.4a	0.6ab	0.8b	0.7ab
HA_2	30.2a	34.2a	32.2a	3.1a	4.3a	3.7a	0.7a	0.9ab	0.8a
HA_3	29.9ab	34.4a	32.1a	2.8a	4.2a	3.7a	0.6ab	1.0a	0.8a
Mean	29.6B[c)]	33.1A		2.8B	4.1A		0.6B	0.9A	
HA	*	*		*	*		*	*	
Soil	*	*		*	*		*	*	
HA × soil	ns[d)]	ns		ns	ns		ns	ns	

*Significant at $P \leq 0.05$.
[a)]HA at 0 (control without HA, HA_0), 30 (HA_1), 60 (HA_2), and 90 (HA_3) mg kg^{-1} soil.
[b)]Values followed by the same lowercase letter in a column are not significantly different at $P \leq 0.05$.
[c)]Values followed by the same uppercase letter in a row within a parameter are not significantly different at $P \leq 0.05$.
[d)]Not significant.

Nutrient contents in plants

The contents of K and N in wheat plants were significantly affected ($P \leq 0.05$) by HA application in both soils (Table III). The highest plant N content was found when 60 mg kg^{-1} of HA was applied for both Raisalpur (17 g kg^{-1}) and Guliana (19 g kg^{-1}) soils. The contents of P remained unaffected by HA application in both soils. The increasing HA levels had a negative effect on K and N concentration; *i.e.*, minimum contents were observed where the highest HA level (HA_3) was applied.

Significant differences among HA levels were found only for N content when averaged across both soils (Table III). Maximum N content (18 g kg^{-1}) was recorded where HA_2 was applied. Similarly, averaged across HA levels, K content was at par between both soils while N and P were significantly higher in the Guliana soil. The interaction effect between HA levels and soil types was found significant only for N concentration.

Soil chemical properties and nutrient concentrations

The chemical properties and nutrient concentrations in both soils after harvest are presented in Table IV. Statistical analysis showed significant differences ($P \leq 0.05$) among HA levels for K concentration in both soils while pH and EC remained unaffected (Table IV). However, in the Guliana soil pH was reduced from 8.0 in the control treatment (HA_0) to 7.9 where HA_2 was applied although the differences were not significant between HA levels. The higher levels of HA

TABLE III

Effect of humic acid (HA) on nutrient contents in wheat plants grown in the Raisalpur (calcareous) and Guliana (non-calcareous) soils tested

HA level[a)]	K			N			P		
	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean
	g kg^{-1}								
HA_0	3	3	3	7c[b)]	12c	10c	2	3	2
HA_1	3	3	3	11b	14b	12b	1	3	2
HA_2	3	2	3	17a	19a	18a	2	3	2
HA_3	2	2	2	11b	14b	12b	2	3	2
Mean	3	3		11B[c)]	15A		2B	3A	
HA	ns[d)]	ns		*	*		ns	ns	
Soil	ns	ns		*	*		*	*	
HA × soil	ns	ns		*	*		ns	ns	

*Significant at $P \leq 0.05$.
[a)]HA at 0 (control without HA, HA_0), 30 (HA_1), 60 (HA_2), and 90 (HA_3) mg kg^{-1} soil.
[b)]Values followed by the same lowercase letter in a column are not significantly different at $P \leq 0.05$.
[c)]Values followed by the same uppercase letter in a row within a parameter are not significantly different at $P \leq 0.05$.
[d)]Not significant.

TABLE IV

Effect of humic acid (HA) on pH, electrical conductivity (EC), and K concentration in the Raisalpur (calcareous) and Guliana (non-calcareous) soils tested

HA level[a]	pH			EC			K			P			NO_3-N		
	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean	Raisalpur soil	Guliana soil	Mean
				dS m^{-1}			mg kg^{-1}								
HA_0	8.1	8.0	8.0	0.26	0.22	0.24	98ab[b]	113ab	105.5ab	11.8	7.2	9.4	0.6	0.6	0.6
HA_1	8.2	7.1	8.0	0.22	0.19	0.20	103a	115a	109.0a	13.9	7.3	10.6	0.6	0.5	0.5
HA_2	8.1	7.9	7.9	0.24	0.21	0.22	95b	108bc	101.5b	13.0	7.8	10.3	0.5	0.5	0.5
HA_3	8.1	7.9	8.0	0.24	0.25	0.24	95b	107c	101.0b	13.7	8.1	10.8	0.6	0.4	0.5
Mean	8.1A[c]	7.9B		0.24	0.21		97B	110A		13.1A	7.5B		0.6A	0.5B	
HA	ns[d]	ns		ns	ns		*	*		ns	ns		ns	ns	
Soil	*	*		ns	ns		*	*		*	*		*	*	
HA×soil	ns	ns		ns	ns		ns	ns		ns	ns		ns	ns	

*Significant at $P \leq 0.05$.

[a] HA at 0 (control without HA, HA_0), 30 (HA_1), 60 (HA_2), and 90 (HA_3) mg kg^{-1} soil.

[b] Values followed by the same lowercase letter(s) in a column are not significantly different at $P \leq 0.05$.

[c] Values followed by the same uppercase letter in a row within a parameter are not significantly different at $P \leq 0.05$.

[d] Not significant.

(HA_2 and HA_3) had negative effects on K concentration in both soils: K concentration decreased from 103 and 115 mg kg^{-1} for HA_2 to 95 and 107 mg kg^{-1} where HA_3 was applied in the Raisalpur and Guliana soils, respectively. Maximum concentration of K was found at HA_1 in both soils. However, higher K concentration (115 mg kg^{-1}) was recorded in the Guliana soil than in the Raisalpur soil (103 mg kg^{-1}).

The average concentration of K significantly increased with HA applications (Table IV). Maximum K concentration (109 mg kg^{-1}) was recorded for HA_1 when averaged for both soils. The soils had significant effect on pH: Significant reduction in pH was recorded in the Guliana soil as compared with the Raisalpur soil. The interactions of HA $\times$ soil did not show a significance effect ($P \leq 0.05$) on chemical properties and K concentration.

Application of different levels of HA had no significant ($P \leq 0.05$) effect on P and NO_3-N concentrations in both soils (Table IV). Following the application of HA, the P concentration in the Raisalpur soil was increased from 11.8 at HA_0 to 13.9 mg kg^{-1} at HA_1 but the difference was not significant. A similar trend was also observed for the Guliana soil. P and NO_3-N concentrations remained unaffected statistically by HA levels. However, significant differences were recorded for P and NO_3-N concentrations between the two soils. Maximum P and NO_3-N, averaging 13.1 and 0.59 mg kg^{-1}, respectively, were observed in the Raisalpur soil. The interaction effect between the HA levels and soils was found statistically non-significant ($P \leq 0.05$) for nutrient concentrations.

DISCUSSION

Wheat growth

In the present investigation, application of humic acid (HA) significantly increased wheat growth in both calcareous and non-calcareous soils. Among different HA levels, application of 60 mg kg^{-1} soil (HA_2) resulted in the highest plant height and shoot fresh and dry weights. The relative increases in plant height and shoot fresh and dry weights (average of both soils) were 10%, 25%, and 18%, respectively, for HA_2 when compared with HA_0. The increase in plant growth due to HA application was also reported previously (Taha *et al.*, 2006; Çelik *et al.*, 2008). The results indicated that the medium dose of HA (60 mg kg^{-1} soil) was either more efficient in promoting growth or at par with higher doses (Table II). These findings were similar to those reported by Lee and Bartlett (1976). Malik and Azam (1985) reported that HA of 54 mg kg^{-1} soil to the water in which wheat seedlings were grown caused significant increase in the growth of roots and shoots as well as uptake of water and nutrients. Tan and Nopamornbodi (1979) concluded that modest amounts of humic acids were beneficial for the root and shoot growth of the corn plants. Pilanali and Kaplan (2003) found that growth and nutrient uptake of strawberry remained unaffected by 400 kg ha^{-1} of humic acid application in a calcareous soil.

Effect of soils on wheat growth was significant. The non-calcareous soil showed the highest plant height, and shoot fresh and dry weights, with relative increases of 13%, 46% and 41%, respectively, over the calcareous soil. So the decrease in growth observed in the calcareous soil may not be associated with the low amount of nutrients supplied by HA. It might be associated with the detrimental physicochemical and biological conditions of the calcareous soil (Brannon and Sommers, 1985; Sharif *et al.*, 2002). Mengel and Kirkby (1982) reported that the high carbonate content and excessive Ca^{2+} concentration in the soil solution and high pH level are the characteristics of calcareous soils. All these soil factors led to low solubility of nutrients that in turn induced nutrient deficiencies of plants grown in calcareous soils, resulting poor plant growth (Kacar and Katkat, 2007).

Nutrient contents in plants

Averaged across the two soils, N contents in wheat plants were significantly affected while K and P remained unaffected by different HA levels (Table III). Medium level of HA (HA_2) increased N concentration by 76% in comparison with the control. The HA_3 level decreased N contents by 38% compared to the HA_2 level. The increase in N content with HA application reflected N mineralization in soil. The P content was decreased due to HA application. Many researches reported that efficiency of humic acid depends on treatment levels, growing media, and origin of humic substances (Chen and Aviad, 1990; Sharif *et al.*, 2002; Vaughan and Linehan, 2004). Furthermore, effectiveness of humic acid regardless of its source and type of container soil differed with plant species. Tan and Nopamornbodi (1979) suggested a distinction of the plants into four groups in which corn shows a moderate reaction to humic acid application. Escobar *et al.* (1996) suggested that when leaf nutrient values were below sufficiency ranges, the foliar application of HA become ineffective to promote the uptake and accumulation of nutrients.

The decrease in P content of the plants in the calcareous soil was possibly due to sorption of HA to minerals other than Ca-P surfaces (Jardine *et al.*, 1989). Whereas, in the non-calcareous soil, formation of metal bridges by HA between mineral surfaces and P possibly counteracts the processes that decrease P sorption (Guppy *et al.*, 2005). Plant N and P contents were 29% and 47% more in the non-calcareous soil than the calcareous soil (Table III). HA increases the permeability of cell membrane, which results in increased nutrient uptake and accumulation. The organic materials may indirectly influence N and P supply to plants through promoting growth and activity of N mineralizing and P solubilizing organisms in soils. Liu (1998) found that application of humic acid did not increase K concentration.

Changes in soil chemical properties and nutrient concentrations

Different organic and inorganic fertilizers slightly decreased soil pH due to the release of H^+ ions during nitrification process of fertilizers (Akram, 1978). An insignificant decrease was found in pH and EC of both soils with moderate HA application during this study (Table IV). The higher dose of HA failed to brought any significant decrease in pH and EC of both soils. Decrease in soil pH value by 0.2 to 0.3 units with HA levels of 50 to 300 mg kg^{-1} was reported by Sharif *et al.* (2002). Kutuk *et al.* (2000) determined significant decreases in the pH values of a soil having a $CaCO_3$ content of 8.2 g kg^{-1} with the application of 2 g kg^{-1} humic acid after a one-month incubation period. On an average of the two soils, the K concentration was 3% more with HA_1 and HA_3 than the control without HA and the Guliana soil retained on average 13% more K than the Raisalpur soil (Table IV). However, P and nitrate N concentrations were more in the Raisalpur soil (Table IV). HA application enhanced P concentration in calcareous soils because it decreased precipitation rates of solution Ca-P minerals (Inskeep and Silvertooth, 1988; Grossl and Inskeep, 1991). The ligand competition between P and humate decreases P concentration in non-calcareous soils (Sibanda and Young, 1986).

CONCLUSIONS

It is worthy to note that HA application enhanced wheat growth and nutrient uptake in both calcareous and non-calcareous soils. The experiment results also showed that application of HA at a higher rate failed to enhance growth and nutrient uptake significantly when compared with its low rate application. HA application increased K concentration in soil after crop harvest. These results have the potential to be applicable in wheat growing regions of both soils.

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